SUPERCONDUCTING SOLENOIDS FOR THE MICE CHANNEL*

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Abstract

This report describes the channel of superconducting solenoids for the proposed international Muon Ionization Cooling Experiment (MICE). MICE consists of two cells of a SFOFO cooling channel that is similar to that studied in the level 2 study of a neutrino factory[1]. MICE also consists of two detector solenoids at either end of the cooling channel section. The superconducting solenoids for MICE perform three functions. The coupling solenoids, which are large solenoids around 201.25 MHz RF cavities, couple the muon beam between the focusing sections as it passes along the cooling channel. The focusing solenoids are around the liquid hydrogen absorber that reduces the momentum of the muons in all directions. These solenoids generate a gradient field along the axis as they reduce the beta of the muon beam before it enters the absorber. Each detector solenoid system consists of five coils that match the muon beam coming to or from an absorber to a 4.0 T uniform solenoidal field section that that contains the particle detectors at the ends of the experiment. There are detector solenoids at the beginning and at the end of the experiment. This report describes the parameters of the eighteen superconducting coils that make up the MICE magnetic channel.

THE MICE CHANNEL

MICE is a channel of superconducting solenoids. The magnets in MICE are around the RF cavities, absorbers (liquid or solid) and the primary particle detectors [1], [2]. The MICE superconducting solenoid system consists of eighteen coils that are grouped in three types of magnet assemblies. The two cell cooling channel is 5.50-m long. Each cell consists of a focusing coil pair around an absorber and a coupling coil around the RF cavity that re-accelerates the muons to their original momentum. At the ends of the experiment are uniform field solenoids for the particle detectors and a set of matching coils used to match the muon beam to the cooling cells. Three absorbers are used instead of two in order to shield the detectors from dark currents generated by the RF cavities at high operating acceleration gradients. A layout of the full version of MICE is shown in Figure 1 below.

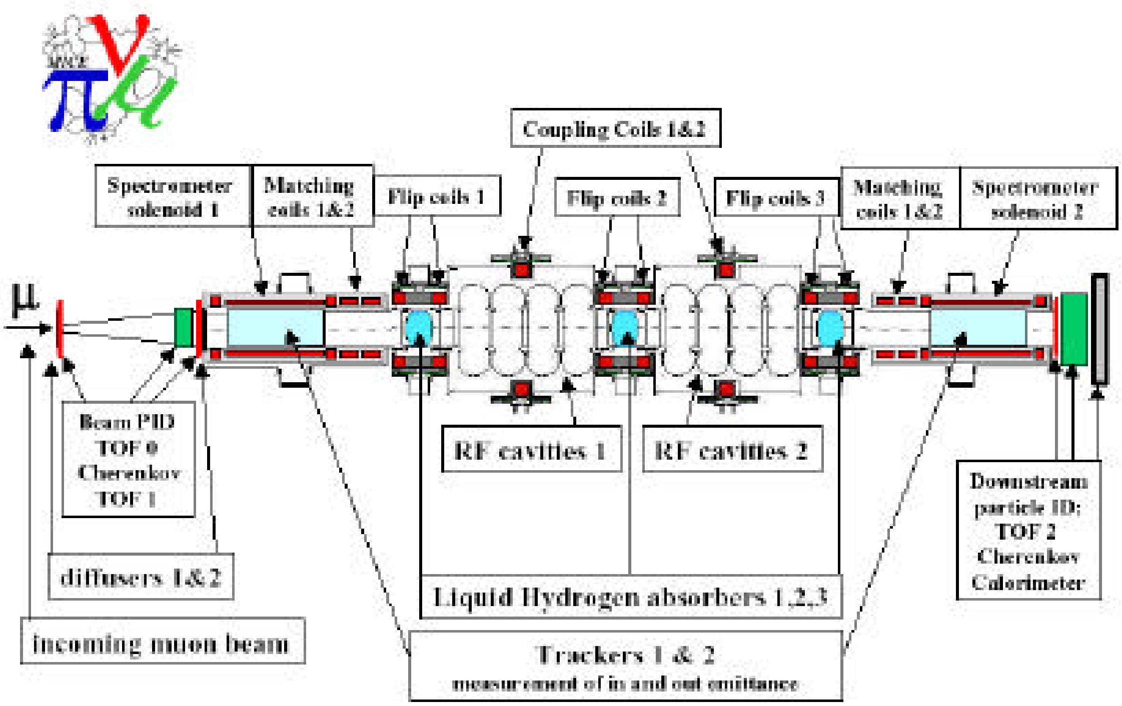

Figure 1. A Schematic Representation of MICE. (The solenoid coils are shown in dark red.)

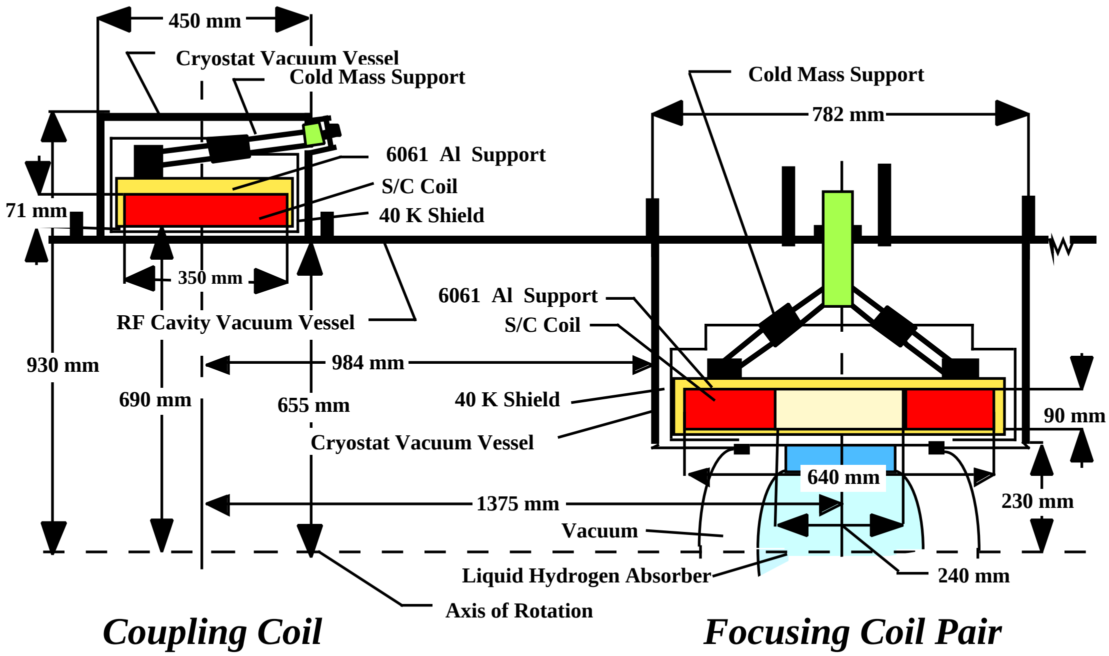

Figure 2. A Quarter Section of a MICE Cooling Cell Showing the Coupling Coil and Focusing Coil Pair

Figure 2 shows a quarter section of a MICE cooling cell. The inner diameter of the coupling coil cryostat is large enough to permit it to be installed around a four cell 201.25 MHz copper RF cavity. The coupling coil controls the beam beta within the RF cavity and matches the muon beam from focusing coil to focusing coil. When the beam beta is low in the center of the focusing coil pair, the current in the coupling coil is low (the beam beta in the RF cavity is large). By varying the current in the focusing coil pair and the coupling coil one can vary the beam beta in the absorber.

The focusing coils (on the right side of Fig 2.) produce a cusp shaped field, with zero field at the center. The design momentum of the MICE channel is 200 MeV/c. The MICE channel average muon momentum is limited by the peak field in the focusing coils. The focusing coil design permits the channel to operate with an average momentum of 240 MeV/c without quenching the magnet. The cusp shaped field in the focusing coils produces large magnetic forces (up to 240 metric tons) that push the coils apart. The focusing coils will have separate leads so that they can be operated either in the solenoid mode or the gradient mode (the cusp field case). The three focusing magnets will be powered using a single power supply. Both coupling coils will be powered using a second power supply. Both supplies produce 10 V and 300 A.

The basic parameters for the focusing coils and the coupling coils are presented in Table 1. The focusing and coupling coils are wound with a MRI superconductor with the following parameters; insulated dimensions 1.0 by 1.65 mm, Cu to S/C ratio = 4, copper RRR = 75, twist pitch = 12.7 mm, filament diameter 78 μm, and J_c(5T,4.2K) = 2940 A mm^{-2}.

Table 1. Focusing and Coupling Magnet Parameters

Parameter	focusing	Coupling
Inner Cryostat R (mm)	230	655
Outer Cryostat R (mm)	668	930
Cryostat Length (mm)	782	500
Inner Coil R (mm)	255	690
Coil Thickness (mm)	90	71
Coil Length (mm)	200	360
D between Coils (mm)	240	-NA-
No. layers per Coil	66	52
No. turns per Coil Layer	121	218
Design Current (A)*	240.3	238.2
Coil Average J (A mm^{-2})*	106.7	105.6
Self Inductance (H)	~45	~230
Peak B in Coil (T)*	6.27	5.45
Temperature Margin (K)*	~1.1	~1.6
Inter-coil Force (MN)	1.82	-NA-

· For channel with p = 200 MeV/c and β = 420 mm

THE DETECTOR MAGNET

At each end of the experiment is a superconducting detector magnet module. The detector magnet module consists of three coils that produce a uniform field (to 3 parts in 1000) of 4 T over a length of 1000 mm and a diameter of 300 mm. Also included in the detector magnet module are two solenoids that match the muon beam to the adjacent focusing magnets. Figure 3 shows a cross-section of the detector solenoid module. Figure 4 shows the field profile on axis as one goes down the MICE channel from one end to the other.

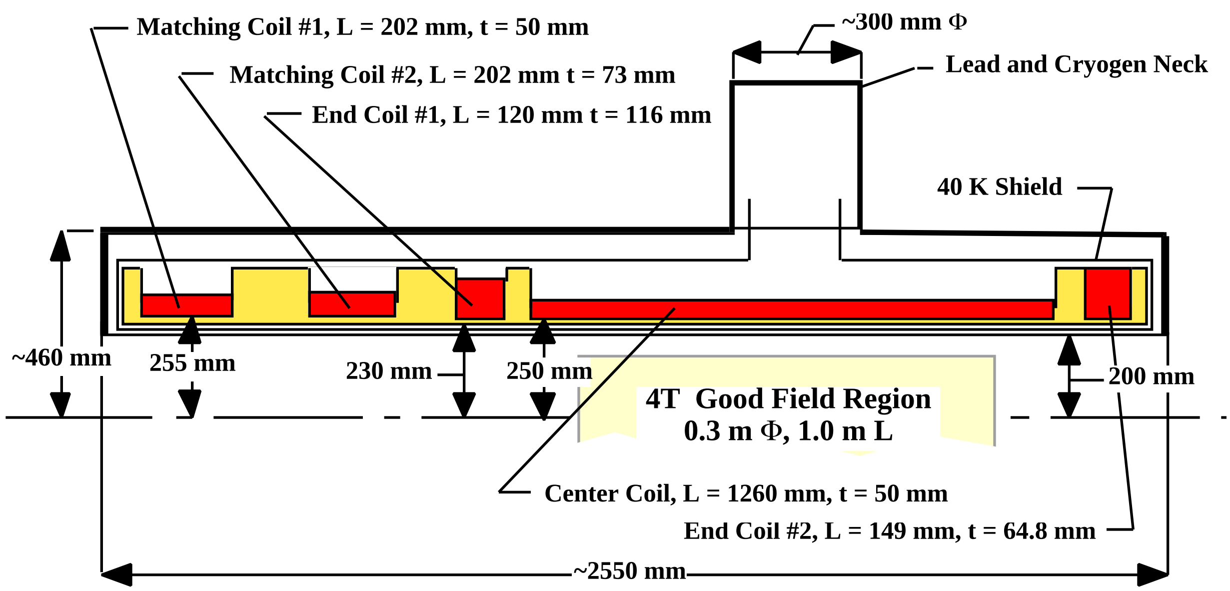

Figure 3. The Upper Half of the INFN Genoa Detector Solenoid Module

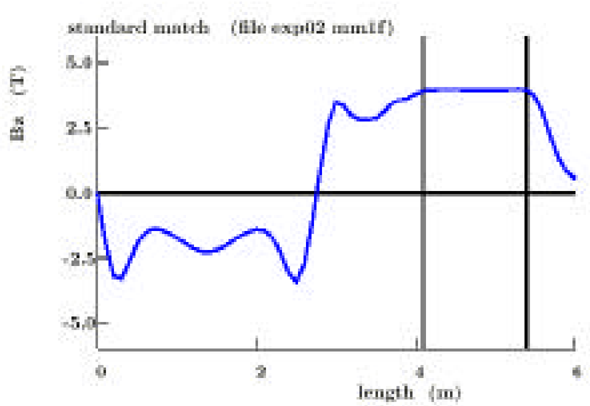

Figure 4. Magnetic Induction on Axis from the center of MICE to the End. B(-x) = -B(x).

In addition, upstream from the first detector there are two low-field muon capture solenoids. These magnets may be conventional or superconducting. These magnets are not shown in Fig.1 nor is their magnetic induction included in Fig. 4.

FORCES BETWEEN COILS

The MICE channel shown in Fig. 1 consists of eighteen superconducting coils. These coils are coupled inductively and mechanically. The cold mass supports for the coupling coils must be designed to carry a longitudinal force of at least 200 kN. The cold mass supports for the focusing coils and the detector coil module must be designed for a force of at least 600 kN.

The cold to warm force on the two outer focusing magnets and the detector magnet modules appears to be strongly dependent on the spacing between the outer focusing coils and the first matching coil. The net force on the focusing magnet module will pull the focusing magnet toward the detector module. The net force on the detector magnet module will pull the detector module toward the focusing magnet.

Further work is needed to determine the forces on the cold-mass support system of all of the magnet modules during the various operating modes of the experiment. The magnetic forces that act on the cold mass supports must be calculated for the magnet currents that occur during a magnet system quench.

ACKNOWLEDGEMENT

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